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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report summarizes research accomplishments in the 3 year period Nov. 1, 1986 – Oct. 31, 1989. The primary accomplishments were in the areas of: (i) signal detection in non-Gaussian noise, including nonparametric and robust detection; (ii) nonlinear edge-preserving filtering of signals in impulsive noise, based on robust estimation procedures; and (iii) applications in constant false alarm rate radar detection and image processing. Reference is made to 27 publications.

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FINAL TECHNICAL REPORT OF RESEARCH

ON

STATISTICAL TECHNIQUES FOR SIGNAL PROCESSING

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Principal Investigator

University of Pennsylvania

Philadelphia, PA 19104

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SUMMARY OF RESEARCH ACCOMPLISHMENTS IN THE PERIOD NOVEMBER 1, 1986 - OCTOBER 31, 1989 UNDER GRANT AFOSR 87-0052, ON STATISTICAL TECHNIQUES FOR SIGNAL PROCESSING

The three-year grant period covered by this report began on November 1, 1986. Advances made during the first year and the second year of this grant period have been described in annual reports dated November 23, 1987 and December 23, 1988.

The primary accomplishments were in the areas of (i) signal detection in non-Gaussian noise, including nonparametric and robust detection; (ii) nonlinear edge-preserving filtering of signals in impulsive noise, based on robu t estimation procedures; and (iii) applications in constant false alarm rate radar detection and image processing.

We now summarize our activity in the third year of effort under the grant which ended on October 31, 1989. In addition, we give a cumulative list of publications and other activity during this three-year grant.

Progress During Third Year of Grant:

One aspect of our work this last year was the continuation and completion of some work we had initiated on nonlinear filtering techniques which are based on order statistics and are generalizations of median filtering. In paper [1], which was published early in the year, we characterized the performance of generalized median filters such as the alpha-trimmed mean and some M-filters, based on the spectral shaping which they impart to the input. Efficient implementation of rank-ordering for use in nonlinear order-statistics filters such as the L-filter (based on linear combination of order statistics) have been given in paper [2]. The recently published paper [3] represents a completion of work we had initiated to develop a class of generalized median filters which are based on the rank estimates of robust statistics. This work shows that in addition to L-filters and M-filters, which are based on the ideas of L-estimation and M-estimation (maximum-likelihood estimation) of statistical theory, the robust R-estimates can also lead to interesting nonlinear R-filters which may have useful applications in image processing, for example. During this last year we also completed work on combining the characteristics of linear finite-impulse-response (FIR) filters and L-filters, which enables one to obtain the advantages of linear filters for frequency domain control as well as those of robustness and edge-preservation from the nonlinear characteristics of the L-filter. This work has recently been submitted for publication [4].

Papers [5] and [6] consider new models for use in the study of signal detection and estimation schemes in non-Gaussian noise. They allow observations to be described as desired signals in additive as well as multiplicative and signal dependent noise. Further work was done on revising and completing these papers last year, and they will appear in mid-1990.

Another focus of our work last year was on the development of detection schemes for use in constant false alarm rate (CFAR) radar detection. CFAR performance is very desirable in high performance radar, and the basic technique is to use a set of observations in a window around the observation in the test cell (a range and/or Doppler frequency value) to set a test threshold. Problems with many existing schemes include target masking in multiple targets, and poor performance at clutter "edges" due to inability of the processor to accurately follow abrupt clutter power transitions. Two new ideas have been investigated. In [7] we applied the idea of trimmed mean processing with variable, data dependent, trimming, and also introduced some new analytical techniques. A recent M.S.E. thesis [8] contains further details of the scheme. In preliminary work in [9] an interesting adaptive or data dependent order statistic based processor is considered, and found to give very good performance characteristics. A full paper is currently being put together to report these new results in more detail.

The principal investigator also made an invited presentation at a Workshop on Robust Techniques in Computer Vision [10], in which various aspects of robust nonlinear filters and their applications were discussed. Finally, work on a Ph.D. dissertation which was supported under this grant was in the final stage last year [11]; this particular Ph.D. will be awarded in 1990.

During the final year of this grant period one graduate research assistant has been supported by the grant and the principal investigator has charged two months of summer salary to the grant.

List of Publications, Third Year of Grant Period

[1]   S. R. Peterson, Y. H. Lee and S. A. Kassam, "Spectral Performance Characteristics of Some Generalized Median Filters," *J. Franklin Inst.,* Vol. 36, No. 1, pp. 151-166, 1989

[2]   R. T. Hoctor and S. A. Kassam, "An Algorithm and a Pipelined Architecture for Order Statistic Determination and L Filtering," *IEEE Trans. Circuits and Systems,* Vol. CAS-36, pp. 344-352, March 1989

[3]   P. P. Gandhi, I. Song and S. A. Kassam, "Nonlinear Smoothing Filters Based on Rank Estimates of Location," *IEEE Trans. Acoustics, Speech, and Signal Processing* , Vol. ASSP-37, pp. 1359-1379, Sept. 1989

[4]   P. P. Gandhi and S. A. Kassam, "Design and Performance of Combination Filters for Signal Restoration," *IEEE Trans. Acoustics, Speech, and Signal Processing,* (Submitted)

[5]   I. Song and S. A. Kassam, "Locally Optimum Detection of Signals in a Generalized Observation Model: The Known Signal Case," *IEEE Trans. Information Theory,* (Accepted for Publication)

[6]   I. Song and S. A. Kassam, "Locally Optimum Detection of Signals in a Generalized Observation Model: The Random Signal Case," *IEEE Trans. Information Theory,* (Accepted for Publication)

[7]   I. Ozgunes, P. P. Gandhi and S. A. Kassam, "A CFAR Detection Scheme Based on Modified Trimmed Mean Thresholding," *Proc. 1989 Conf. Inform. Sciences and Systems (Johns Hopkins Univ.),* pp.   - , March 1989

[8]   I. Ozgunes, "CFAR Detectors Based on Order Statistic Processing," M.S.E. Thesis, Dept. of Elect. Eng., Univ. of Pennsylvania, August 1989

[9]   P. P. Gandhi and S. A. Kassam, "An Adaptive Order Statistic Constant False Alarm Rate Detector," *Proc. IEEE Int. Conf. Systems Engineering,* (Invited Paper), pp. 85-88, August 1989

[10]   S. A. Kassam, "Edge-Preserving Robust Filters for Image Processing Applications," (Invited Presentation), *Proc. Workshop on Robust Estimation in Computer Vision,* Univ. of Maryland, July 1989

[11]   P. P. Gandhi, "Order Statistics and Rank Based Processors for Filtering and Detection," Ph.D. Dissertation, Dept. of Elect. Eng., Univ. of Pennsylvania, (in preparation).

CUMULATIVE LIST OF PUBLICATIONS
NOVEMBER 1, 1986 - OCTOBER 31, 1989

During each of the three years of this grant period, one graduate student was supported as a research assistant by the grant and the principal investigator charged two months of summer salary to the grant.

Books:

[1]   S. A. Kassam, *Signal Detection in Non-Gaussian Noise.*
Springer Verlag, New York, 1988

Papers in Refereed Journals:

[1]   S. A. Kassam, "Nonparametric Hard Limiting and Sign Detection of Narrowband Deterministic and Random Signals," *IEEE J. of Oceanic Engineering,* Vol. OE-12, pp. 66-74, January 1987 *(Invited Paper)*

[2]   S. R. Peterson, Y. H. Lee and S. A. Kassam, "Some Statistical Properties of Alpha Trimmed Means and Standard Type M Filters," *IEEE Trans. Acoustics, Speech and Signal Processing,* Vol. ASSP-36 , pp. 707 - 713, May 1988

[3]   R. T. Hoctor and S. A. Kassam, "A Comparison of Two Methods of Estimating the Intensity of a Noisy Complex Process," *IEEE Trans. Acoustics, Speech and Signal Processing,* Vol. ASSP- 36, pp. 751-756, May 1988

[4]   P. P. Gandhi and S. A. Kassam, "Analysis of CFAR Processors in Non-Homogeneous Background," *IEEE Trans. Aerospace and Electronic Systems,* Vol. AES-24, pp. 427-445, July 1988

[5]   S. R. Peterson, Y. H. Lee and S. A. Kassam, "Spectral Performance Characteristics of Some Generalized Median Filters," *J. Franklin Inst.,* Vol. 36, No. 1, pp. 151-166, 1989

[6]   R. T. Hoctor and S. A. Kassam, "An Algorithm and a Pipelined Architecture for Order Statistic Determination and L Filtering," *IEEE Trans. Circuits and Systems,* Vol. CAS-36, pp. 344-352, March 1989

[7] P. P. Gandhi, I. Song and S. A. Kassam, "Nonlinear Smoothing Filters Based on Rank Estimates of Location," *IEEE Trans. Acoustics, Speech, and Signal Processing* , Vol. ASSP-37, pp. 1359-1379, Sept. 1989

[8] I. Song and S. A. Kassam, "Locally Optimum Detection of Signals in a Generalized Observation Model: The Known Signal Case," *IEEE Trans. Information Theory*, (Accepted for Publication)

[9] I. Song and S. A. Kassam, "Locally Optimum Detection of Signals in a Generalized Observation Model: The Random Signal Case," *IEEE Trans. Information Theory*, (Accepted for Publication)

[10] P. P. Gandhi and S. A. Kassam, "Design and Performance of Combination Filters for Signal Restoration," *IEEE Trans. Acoustics, Speech, and Signal Processing,* (Accepted for Publication)

Conference Proceedings:

[1] P. P. Gandhi and S. A. Kassam, "Analysis and Performance of Rank Filters for Edge Preserving Smoothing," *Proc. 1987 IEEE Int. Symp. on Circuits and Systems,* pp. 264-267, May 1987

[2] S. A. Kassam and S. R. Peterson, "Nonlinear Finite Moving Window Filters for Signal Restoration," *Proc. IEEE Pacific Rim Conf. Comm., Comp. and Sig. Process.,* pp. 17-20, June 1987

[3] I. Song and S. A. Kassam, "Random Signal Detection in a Generalized Observation Model," *Proc. IEEE Pacific Rim Conf. Comm., Comp. and Sig. Process.,* pp. 13-16, June 1987

[4] I. Song and S. A. Kassam, "An Application of Rank Statistics to Random Signal Detection," *Proc. 30th Midwest Symp. on Circuits and Systems,* pp. 1120-1125, August 1987

[5]   I. Song and S. A. Kassam, "Rank Detection of Random Signals in Additive Noise," *Proc. IEEE Region Ten Conf. (TENCON)*, August 1987

[6]   R. T. Hoctor and S. A. Kassam, "An Algorithm for Order Statistic Determination and L-Filtering," *Proc. IEEE Inter. Conf. Acoustics, Speech and Signal Process.,* pp. 1686-1689, April 1988

[7]   P. P. Gandhi, S. R. Peterson and S. A. Kassam, "Frequency Selective Signal Restoration Using Nonlinear Combination Filters," *Proc. IEEE Inter. Conf. Acoustics, Speech and Signal Process.,* pp. 1522-1525, April 1988

[8]   R. T. Hoctor and S. A. Kassam, "An Efficient Structure for Nonlinear L- and C-Filters," *Proc. IEEE Inter. Symp. Circuits and Systems,* pp. 1491-1494, June 1988

[9]   P. P. Gandhi and S. A. Kassam, "Nonlinear C-Filters for Nonstationary Signals and Deconvolution in Impulsive Noise," *Proc. IEEE Inter. Symp. Circuits and Systems,* pp. 1507-1510, June 1988

[10]   I. Ozgunes, P. P. Gandhi and S. A. Kassam, "A CFAR Detection Scheme Based on Modified Trimmed Mean Thresholding," *Proc. 1989 Conf. Inform. Sciences and Systems (Johns Hopkins Univ.),* pp.   - , March 1989

[11]   P. P. Gandhi and S. A. Kassam, "An Adaptive Order Statistic Constant False Alarm Rate Detector," *Proc. IEEE Int. Conf. Systems Eng,* (Invited Paper), pp. 85-88, August 1989

Theses and Dissertations:

[1] R. T. Hoctor, *A Comparison of Two Methods of Estimating the Intensity of a Noisy Complex Process.* M.S.E Thesis, Dept. of Computer and Inform. Sciences, Univ. of Penn., May 1987

[2] I. Song, *Nonlinear Techniques for Detection and Filtering of Discrete-Time Signals.* Ph.D. Dissertation, Dept. of Elect. Eng., Univ. of Penn., May 1987

[3] I. Ozgunes, *CFAR Detectors Based on Order Statistic Processing.* M.S.E. Thesis, Dept. of Elect. Eng., Univ. of Pennsylvania, August 1989

[4] P. P. Gandhi, *Order Statistics and Rank Based Processors for Filtering and Detection.* Ph.D. Dissertation, Dept. of Elect. Eng., Univ. of Pennsylvania, (May 1990).

Invited Workshop Presentations:

[1] P. P. Gandhi and S. A. Kassam, "Nonlinear Filters for Robust Frequency Selective Filtering," *Proc. IEEE Digital Signal Processing Workshop,* Lake Tahoe, October 1988

[2] S. A. Kassam, "Edge-Preserving Robust Filters for Image Processing Applications," *Proc. Workshop on Robust Estimation in Computer Vision,* Univ. of Maryland, July 1989

(Principal Investigator also presented several research seminars and colloquia at universities in the United States)